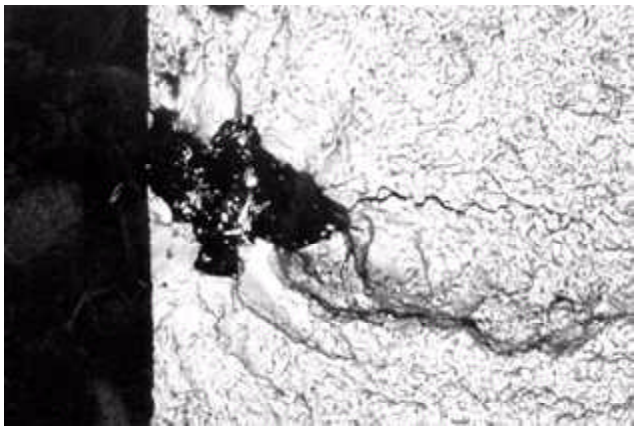
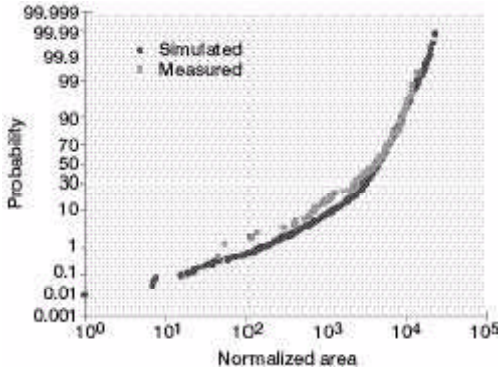
Ceramic Inclusions in Powder Metallurgy Disk Alloys: Characterization and Modeling

Powder metallurgy alloys are increasingly used in gas turbine engines, especially in turbine disk applications. Although powder metallurgy materials have many advantages over conventionally cast and wrought alloys (higher strength, higher temperature capability, etc.), they suffer from the rare occurrence of ceramic defects (inclusions) that are inherent to the powder atomization process. These inclusions can have a potentially large detrimental effect on the durability of individual components. An inclusion in a high stress location can act as a site for premature crack initiation and thereby considerably reduce the fatigue life. Because these inclusions are exceedingly rare, they typically do not reveal themselves in the process of characterizing the material for a particular application (the cumulative volume of the test bars in a fatigue life characterization is typically on the order of a *single* actual component). Ceramic inclusions have, however, been found to be the root cause of a number of catastrophic engine failures. To investigate the effect of these inclusions in detail, we have undertaken a study where known populations of ceramic particles, whose composition and morphology are designed to mimic the "natural" inclusions, are added to the precursor powder. Surface-connected inclusions have been found to have a particularly large detrimental effect on fatigue life; therefore, the quantity of ceramic "seeds" added is calculated to ensure that a minimum number will intersect the surface of the fatigue test bars. Because the ceramic inclusions are irregularly shaped and have a tendency to break up in the process of extrusion and forging, a method of calculating the probability of occurrence and expected intercepted surface area was needed. We have developed a Monte Carlo simulation to determine the distributions of these parameters and have verified the simulated results with observations of ceramic inclusions found in macroscopic slices from extrusions and forgings. Fatigue specimens have been machined from Udimet 720 (a powder metallurgy superalloy) forgings, to determine the effects of the inclusions on fatigue life. The ultimate goal of this study will be to use probabilistic methods to determine the reliability detriment that can be attributed to these ceramic inclusions. This work has been supported by the Ultra Safe and Ultra-Efficient Engine Technologies programs.



Crack emanating from a surface-connected ceramic inclusion.



Comparison of observed and simulated intercepted surface area of seeded ceramic inclusions.

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